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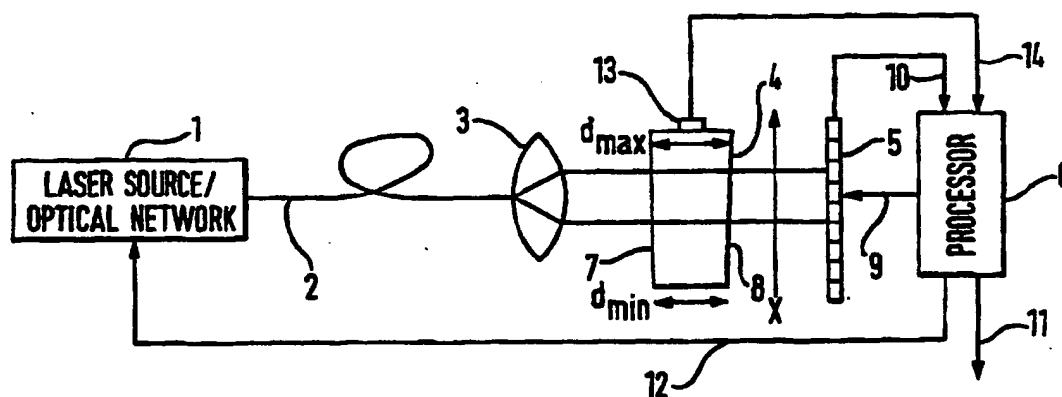
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## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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(54) Title: OPTICAL WAVELENGTH SENSOR



## (57) Abstract

An optical wavelength sensor consists of a wedge shaped Fabry Perot etalon (4) which exhibits resonance for different optical wavelengths across its width (X), and an array of detectors  $x_n$  that detects the spatial disposition of resonant peaks which occur in the etalon, for comparison with stored peak patterns in a processor (6), so as to determine the spectral content of the incident light from an optical fibre (2).

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## Optical Wavelength Sensor

### Field of the Invention

This invention relates to an optical wavelength sensor which has particular but not exclusive application to use in an optical data transmission network for monitoring channel transmission frequencies.

### Background to the Invention

In order to cope with the increasing demand for subscriber services on telecommunication networks, digital optical transmission networks are being introduced in which local access networks, which typically route electrical signals, are interconnected by a fibre optic network. In order to upgrade the capacity of the optical network, wavelength division multiplexing (WDM) techniques have been proposed, which permit the transmission capability of the fibre link to be upgraded to the multi-G bit/s range.

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In a WDM system, a number of different wavelength channels are transmitted simultaneously in an optical fibre, each channel being defined typically by a laser source.

In order for the transmission system to operate reliably, it is desirable to monitor the channel wavelengths. Present methods of measuring wavelength involve optical spectrum analysers, wave meters or gas absorption techniques. These known methods however can presently only be used in a laboratory and are expensive or impractical to implement in a telecommunications network.

25

A known wavemeter is described in " Low cost wavemeter with a solid Fizeau interferometer and fiber optic input" B. Faust et al, Applied Optics., Vol 30 No 36, 20 December 1991. The wavemeter comprises a resonant cavity in the form of a Fizeau wedge which exhibits resonance for different optical wavelengths at spaced locations therein. The wedge operates in reflection, in

30

response to optical radiation from an optical fibre, to direct radiation of different wavelengths to an array of detectors for detecting said different wavelengths from said spaced cavity locations. However, with such wavemeters that operate in reflection, there is an inherent limitation on the wavelength resolution that can be achieved and it would be difficult to use the known wavemeter to resolve WDM channels in an optical telecommunications system.

A wavemeter that operates in transmission, using a Fabry-Perot etalon is described in "A simple real-time wavemeter for pulsed lasers" Ja-Yong Koo et al, Measurement Science And Technology, Vol 2, No 1, January 1991, pp 55-58. This device can resolve extremely fine wavelength variations and for example can discern 10Hz wavelength jitter in a pulsed laser output. The laser radiation impinges on a Fabry Perot etalon that has parallel semireflective faces. A resulting fringe pattern in the form of circular rings, is imaged onto a detector array by a lens. The pattern of the rings shifts with very small changes in wavelength. However, for larger changes in wavelength, such as a few nm, that occurs between WDM channels, very substantial changes in the ring pattern would occur and would not be trackable in order to monitor the wavelength.

### Summary of the Invention

According to the present invention there is provided a wavelength sensor with a cavity that comprises a Fabry Perot etalon having semireflective faces that produce multiple reflections therein, the cavity having a non-uniform thickness between the faces so as to produce said resonance at spaced locations for different wavelengths.

The semireflective faces may be disposed in a non-parallel configuration to provide the non-uniform cavity thickness.

The sensor may include input means to direct optical radiation into the cavity

on one side thereof through one of said faces in an axial direction, said detector array extending transversely of the axial direction on another side of the cavity to detect radiation emanating from the cavity through the other of the faces.

5

The sensor according to the invention may conveniently be included in an optical telecommunications network for monitoring the wavelength of one or more transmission channel, for example in a WDM system. The sensor may be used to provide an alarm when the wavelength of a particular channel  
10 moves outside of predetermined limits. Also, the sensor may be used to control the wavelength produced by the optical source, for example in a feedback loop.

Thus, the invention provides a simple and convenient sensor which may  
15 readily be incorporated into an optical transmission network for detecting the wavelengths of WDM channels.

#### **Brief Description of the Drawings**

In order that the invention may be more fully understood, an embodiment  
20 thereof will now be described by way of example with reference to the accompanying drawings, in which:

Figure 1 is a schematic block diagram of an optical wavelength sensor in accordance with the invention, embodied in an optical telecommunications network; and

25 Figure 2 is a graph illustrating the outputs of the array of detectors shown in the direction X of Figure 1.

#### **Description of an Embodiment of the Invention**

Referring to Figure 1, the source 1 of optical radiation, shown schematically,  
30 may comprise a multi-wavelength source, which produces a plurality of transmission channels in an optical transmission network. The output of the source 1 is directed into an optical fibre 2 coupled to the network. The

source 1 may in practice comprise a plurality of laser sources each operating at a respective different wavelength, with individual modulators that produce an optical modulated bit stream transmitted through the optical fibre 2. The individual laser sources may typically be at a plurality of remote locations and  
 5 it may be desirable to monitor the wavelength of the various transmission channels to ensure that the telecommunications network is operating according to its design specification.

10 The optical wavelength sensor shown in Figure 1 comprises a lens 3, a Fabry Perot etalon 4, a detector array 5 and an output processor 6. The Fabry Perot etalon 4 consists of a block of optically transmissive material having semireflective planar facets 7, 8. The construction of a Fabry Perot etalon is well known *per se* and etalons are typically used as filters. The body of the  
 15 etalon operates as a resonant cavity and the semireflective surfaces produce multiple reflections within the body so as to create a resonance. Resonance occurs at a particular wavelength, dependent upon the refractive index of the body and spacing between the semireflective surfaces which can be approximately characterised as follows:

$$20 \qquad n\lambda_r = 2\mu d \qquad (1)$$

where  $\lambda_r$  is the resonant wavelength  
 $\mu$  is the refractive index of the cavity material at the resonant wavelength  
 $d$  is the thickness of the cavity between the semireflective facets  
 25  $n$  is a positive integer.

In a conventional Fabry Perot etalon, the facets 7 and 8 are parallel to one another so that the etalon exhibits a resonance for a single wavelength peak. However, in accordance with the invention, the etalon shown in Figure 1 is  
 30 slightly wedge shaped, so that the facets 7, 8 are slightly out of parallel. Thus, the thickness of the etalon varies between a minimum value  $d_{min}$  and a maximum value of  $d_{max}$ . As a result, a resonant cavity is provided which

exhibits a resonance for different optical wavelengths at spaced locations in the direction X across the width of the etalon, normal to the direction of the incident optical beam.

- 5 The lens 3 acts as a beam spreader so as to spread the beam from the optical fibre 2 across the width of the etalon.

The etalon may be made of silica or other suitable materials according to techniques well known *per se*. The wedge angle and the thicknesses  $d_{min}$  and  
 10  $d_{max}$  are selected according to the range of wavelengths to be detected and can be determined by routine methods as will readily be apparent to those skilled in the art. The device may typically be configured to discriminate between WDM channels within the usual optical telecommunication wavelength bandwidths centered on 1300 or 1500 nm

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The array of detectors 5 comprises a linear array of detectors  $x_1, x_2 \dots x_n$  which may comprise CCD devices arranged in the direction X across the width of the incident optical beam. In this example the detectors are serially clocked by a clocking signal C1 produced by the output processor 6 on line 9  
 20 so that the outputs of the detectors are fed serially on line 10 to the output processor. Also, the array of detectors 5 may comprise comprise a photodiode array. Suitable arrays are available commercially as will be evident to those skilled in the art.

- 25 The output of the detectors  $x_1 - x_n$  for wavelengths  $\lambda_1$  and  $\lambda_2$  is shown in Figure 2. Considering the wavelength  $\lambda_1$ , the resonant condition defined by equation (1) occurs for two different values of the etalon thickness d in the direction X across the incident beam at detector positions  $x_{\lambda 1,1}$   $x_{\lambda 1,2}$ . For the second wavelength  $\lambda_2$ , resonance occurs at different detector positions  $x_{\lambda 2,1}$ ,  
 30  $x_{\lambda 2,2}$ . Thus, the spacings of the resonances  $x_{\lambda 1,1}$ ,  $x_{\lambda 2,1}$  or  $x_{\lambda 1,2}$ ,  $x_{\lambda 2,2}$  provide a measure of the wavelength of the incident beam. It will be seen that the output from the detector array 5 can be readily digitised and



compared in the output processor 6 with predetermined patterns held in a digital memory. The pattern and relative disposition of the resonant peaks thus provides an indication of the channel wavelengths incident from the optical fibre 2. The processor 6 can thus provide an output on line 11  
5 indicative of the channel wavelengths and also can provide an indication of when each channel wavelength moves outside of a predetermined wavelength range, so as to monitor the integrity of data transmission in the network.

Typically, the laser sources 1 are at remote locations so that it will not be  
10 readily possible to adjust the sources. However, if at least one laser source is proximate to the wavelength detector for example being in the same exchange building, it is possible to provide feedback on line 12 to the laser source so as to control its wavelength in a feedback loop, so as to keep its emission wavelength within a predetermined range.

15 As previously mentioned, the etalon 4 is preferably made of a material which has a low dependence of optical length on temperature so as to minimise changes in the product  $\mu d$  with temperature. It will be seen from equation (1) that changes of the product  $\mu d$  as a function of temperature will alter the  
20 position at which the resonant peaks occur as a function of temperature. Preferably, the etalon is made of material such as fused silica for temperature stability. Furthermore, temperature compensation can be achieved by means of a temperature sensor 13, attached to the cavity 4 which provides a signal on line 14 to the processor 6 in order to permit the processor to compensate the  
25 signals on lines 11, 12 as a function of temperature. Alternatively, or additionally, the etalon may be provided with some means, such as a Peltier element, to control the etalon's temperature.

Thus, by means of the described arrangement, it is possible to monitor the  
30 individual channel wavelengths of a WDM optical network. The detector may be initialised by firstly transmitting a known reference frequency through the optical fibre 2 to provide datum positions for the resonant peaks.

As used herein, in both the description and the claims, the term "optical" includes visible light and non visible radiation such as ultra-violet and infrared radiation.

## Claims

1. An optical wavelength sensor comprising a resonant cavity (4) which  
5 exhibits resonance for different optical wavelengths at spaced locations therein,  
and an array of detectors ( $x_n$ ) for detecting said different wavelengths from  
said spaced cavity locations characterised in that the cavity (4) comprises a  
Fabry Perot etalon having semireflective faces (7, 8) that produce multiple  
reflections therein, the cavity having a non-uniform thickness (d) between said  
10 faces so as to produce said resonance at spaced locations for different  
wavelengths.
2. A sensor according to claim 1 wherein the semireflective faces (7, 8)  
are disposed in a non-parallel configuration whereby to provide said non-  
15 uniform cavity thickness.
3. A sensor according to claim 1 or 2 including input means (2) to direct  
optical radiation into the cavity (4) on one side thereof through one of said  
faces (7) in an axial direction, said detector array extending transversely of the  
20 axial direction on another side of the cavity to detect radiation emanating  
from the cavity through the other of the faces (8).
4. A sensor according to claim 3 including means (3) for spreading the  
radiation from the input means (2) transversely of the axial direction across  
25 the cavity for resonance therein.
5. A sensor according to claim 4 wherein the input means comprises an  
optical fibre (2) and the spreading means comprises a lens (3) disposed in the  
optical path between the fibre and the cavity.  
30
6. A sensor according to any preceding claim wherein the array of

detectors comprises an array of CCD detectors (5).

7. A sensor according to any preceding claim including a source of optical radiation (1) to be directed to the cavity, and output means (6) responsive to the detector array for controlling an operational characteristic of the source.

8. A sensor according to any preceding claim including output means (11) responsive to the detectors for providing a given output when the wavelength characteristic of optical radiation incident on the cavity departs from a predetermined characteristic.

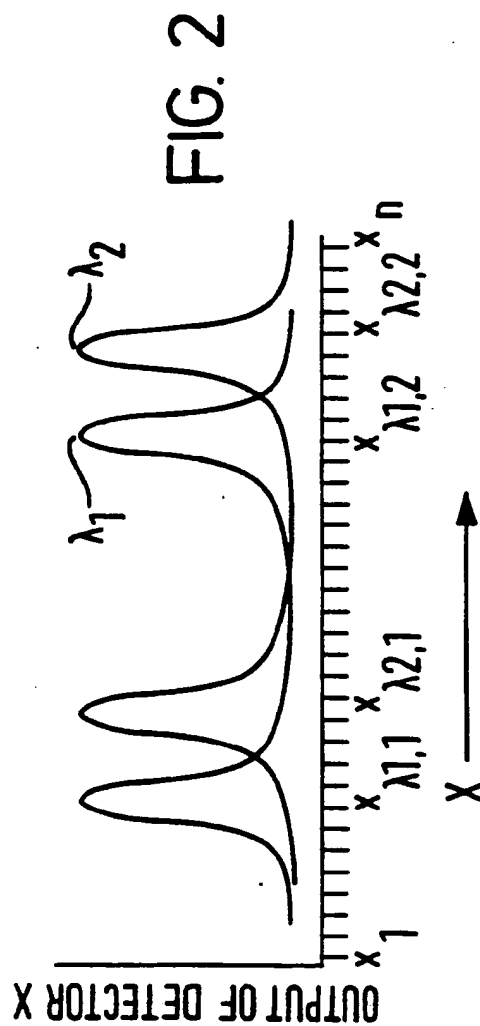
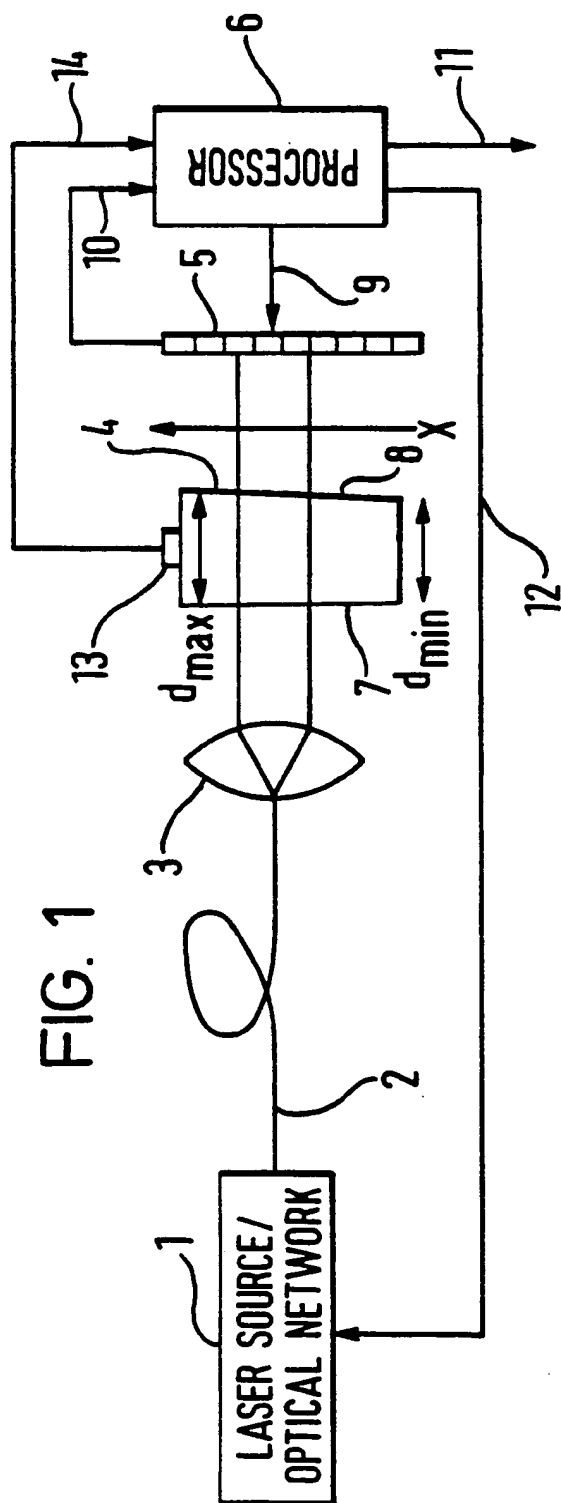
9. A sensor according to any preceding claim including temperature sensing means (13) for sensing the cavity temperature, and compensating means (6) for compensating the output of the output means for changes in the sensed wavelength produced by changes in cavity temperature.

10. A sensor according to any preceding claim wherein the cavity (4) is made of fused silica.

11. A WDM optical network including a detector according to any preceding claim for detecting the wavelengths of at least one of the WDM channels.

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FIG. 1



# INTERNATIONAL SEARCH REPORT

International Application No  
PCT/GB 95/00094

A. CLASSIFICATION OF SUBJECT MATTER  
IPC 6 G01J9/02 H01S3/133

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
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Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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## C. DOCUMENTS CONSIDERED TO BE RELEVANT

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| Y          | <p>APPLIED OPTICS.,<br/>vol.30, no.36, 20 December 1991, NEW YORK<br/>US<br/>pages 5254 - 5259<br/>B.FAUST ET AL. 'Low-cost wavemeter with a<br/>solid Fizeau interferometer and<br/>fiber-optic input'<br/>see page 5254; figures 1,2,4,5<br/>see page 5256, right column, paragraph 2 -<br/>page 5258, left column, paragraph 1<br/>---<br/>-/--</p> | 1-11                  |

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| Category *   | Citation of document, with indication, where appropriate, of the relevant passages   | Relevant to claim No. |
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| Y  | <p>K MUTZE ET EL. 'ABC DER OPTIK'<br/>1972 , WERNER DAUSIEN VERLAG , HANAU/MAIN,<br/>DE<br/>see page 239, left column, last paragraph<br/>- right column, paragraph 1</p> <p style="text-align: center;">---</p>   | 1-11                  |
| A  | <p>IEEE PHOTONICS TECHNOLOGY LETTERS,<br/>vol.5, no.2, February 1993, US<br/>pages 186 - 189<br/>Y.C.CHUNG ET AL. 'Synchronized Etalon<br/>Filters for Standardizing WDM Transmitter<br/>Laser Wavelengths'<br/>see page 186 - page 187, right column,<br/>paragraph 2; figures</p> <p style="text-align: center;">---</p>     | 11                    |
| A  | <p>JOURNAL OF LIGHTWAVE TECHNOLOGY,<br/>vol.LT-5, no.9, September 1987, NEW YORK,<br/>US<br/>pages 1301 - 1308<br/>K.NOSU ET AL. 'Optical FDM Transmission<br/>Technique'<br/>see paragraph IV; figures 9-12</p> <p style="text-align: center;">-----</p>  | 7-9                   |